SOME DIFFERENCES BETWEEN THE MET 0 20 5 AND 11 LAYER MODEL ANNUAL CYCLE INTEGRATIONS

by

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Abstract

January and July simulations from multi annual integrations made with the Meteorological Office 5 and 11 layer models are compared. The differences between the simulations are discussed and, where possible, explained in terms of the model formulations. The model integrations are also compared with climatological data, and the most serious model errors are considered.

Introduction

For short term forecasting, the quality of the initial data and the accurate representation of atmospheric dynamics are of prime importance. As the range of the forecast is increased, it becomes more important that the model has a realistic climatology. Errors in the model climatology may not only arise through shortcomings in the model's dynamics, but also through deficiencies in the parameterization of physical processes such as radiation, which are effective over a longer time scale. A knowledge of the difference between the model and observed climatology alone may not indicate the change required in the model. It is more instructive to study how this difference varies between models. In this paper, the simulations from the Meteorological Office 5 and 11 layer models are compared and discussed. Where possible, the differences are explained in terms of the model formulations.

The 5 layer model (5LM) has been integrated for 40 months, and the 11 layer model (11LM) for 12 months. Both models incorporate the seasonal variation of solar radiation, sea surface temperatures, sea-ice extents, ozone amounts and cloud cover (which is zonally averaged in each model). This descriptive note records the main differences in the simulation of climate by the two models. For brevity, only the July and January climates will be considered in detail.

The basic 5LM has been described by Corby, Gilchrist and Rowntree (1977), and Slingo (1980) includes details of the amendments which were made to incorporate soil moisture and snow variables and an annual cycle. Details of the prescribed zonally averaged ozone and cloud are given by Bolton (1977, 1981). Various aspects of the integration have been considered by Farmer (1979, surface pressure), Slingo (1979, radiation), and Mitchell (1981a, zonally meaned surface pressure and precipitation, 1981b, hydrology). The basic 11LM is described by Saker (1975). Other aspects are described by Lyne and Rowntree (1976, convection), and Walker (1977, radiation and 1978, cloud). The specification of cloud and ozone amounts was similar to the 5LM. An assessment of the precipitation patterns has been made by Cunnington (1979). A summary of the main differences in the models' grids, and their treatment of the surface, the boundary layer, radiation, convection and diffusion are shown in Table 1.

More than one integration is needed to establish the climatology of the model for a particular month, as each model has an inherent internal variability. This variability should be taken into account when comparing results from different models. Most of the differences discussed in this paper are apparent in other integrations which have been made with the two models but are not described here.

In some instances, only the July simulations will be compared as climate in the northern hemisphere is less variable then than in January, and differences are less likely to be due to the models' inherent variability.

Table 1

MAIN DIFFERENCES IN MODEL FORMULATIONS

GRID 5 LAYER MODEL	11 LAYER MODEL
5 layers, equally spaced 330 km in horizontal	11 layers, concentrated near surface, tropopause 220 km
BOUNDARY LAYER	
1 layer (up to $\sigma = 0.8$) Explicit boundary layer height Bulk aerodynamic formula Stable/unstable land/sea drag coefficient Full evap. when soil moisture = 10 cm Run off when soil moisture = 20 cm	3 layers (up to $\sigma = .79$) Vertical diffusion, "Clarke" scheme Drag coefficient continuous function of stability and roughness length Full evaporation - 5 cm Runoff - 15 cm
RADIATION	
Temperature and humidity interpolated to 10 equally spaced layers for radiation Snowfree albedo a function of latitude Albedo over snow a function of snow depth	Fluxes calculated on model layer boundaries Reflected solar beam absorbed Constant (= .2) Constant (=.5)
Cloud amounts, albedos similar	
PENETRATIVE CONVECTION	
Detrains only at upper levels May affect a given layer more than once/timestep	May entrain and detrain at any level Only affects a given layer once/timestep
DIFFUSION	
Non linear diffusion of humidity	Linear diffusion of humidity

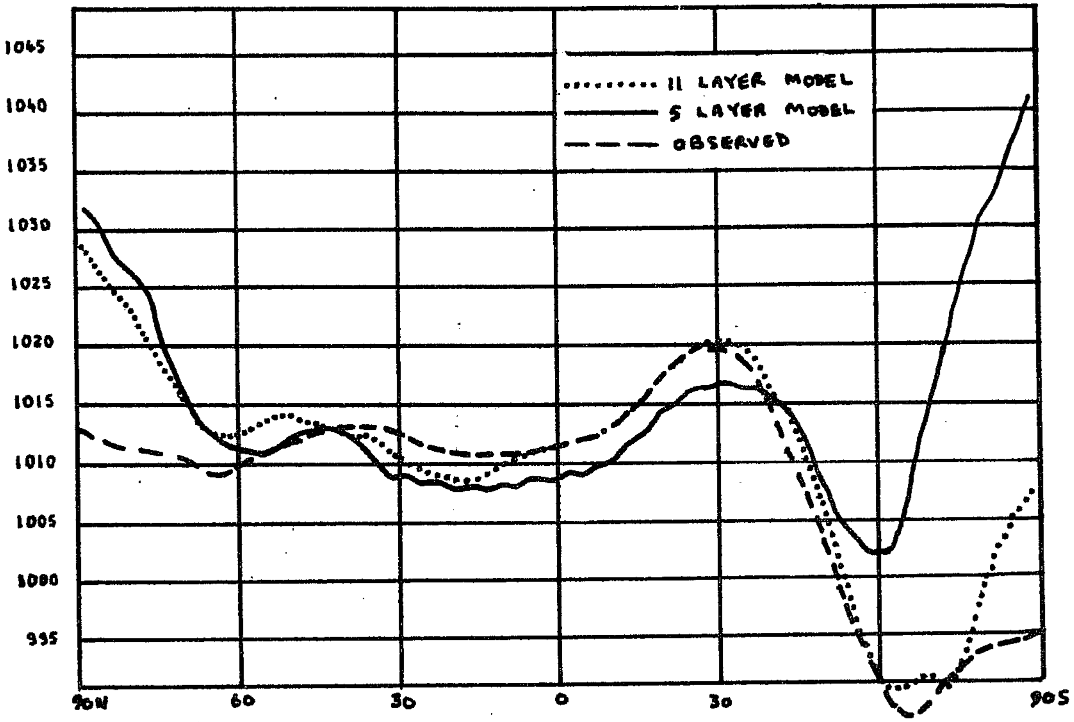
2. Simulation of surface pressure

Both models produce higher pressure than observed over the summer pole (Fig.1). The 11LM produces a deeper (and more realistic) southern circumpolar trough throughout the year. This is positioned further south in the 11LM, especially in July. Both models, particularly the 11LM, produces westerly flow in northern mid-latitudes in winter which is stronger than observed. The loweer surface pressure found near the winter pole in the 11LM simulation may result from the finer vertical and horizontal resolution. Increasing the horizontal resolution in the 5LM produced generally lower pressure over the winter pole (Hills, 1978, 1982). The southern hemisphere subtropical ridge is found further south in the 11LM, and is stronger, especially in January. In general, the surface pressure in the 11LM is higher in low latitudes and lower in high latitudes.

In July the 11LM generates much lower pressure (for low latitudes) over southeast Asia and the adjoining sea areas (Fig.2). The pressure is some 5 mb lower than observed (Fig.2(d)) in the Bay of Bengal, and 10 mb lower than observed to the south of Japan. The model also produces excessive convective rainfall in these regions (see later). The Azores anticyclone is further south, and the Pacific anticyclone is weaker than in the 5LM, giving a band of lower pressure over the oceans near 45°N.

In January, the northern continental anticyclones are much stronger in the 11LM simulation (Fig.3), and the main cells over Spain and eastern Asia are found further poleward. This gives a more realistic representation of the Siberian anticyclone (Fig. 3(d)), but exaggerates the westerly flow over Europe. The pressure in the 11LM is generally higher in low latitudes, but note the relative troughs over the ocean east of Madagascar and northeast of Australia which may arise from or contribute to the excess precipitation found there.

(a) July



(b) January

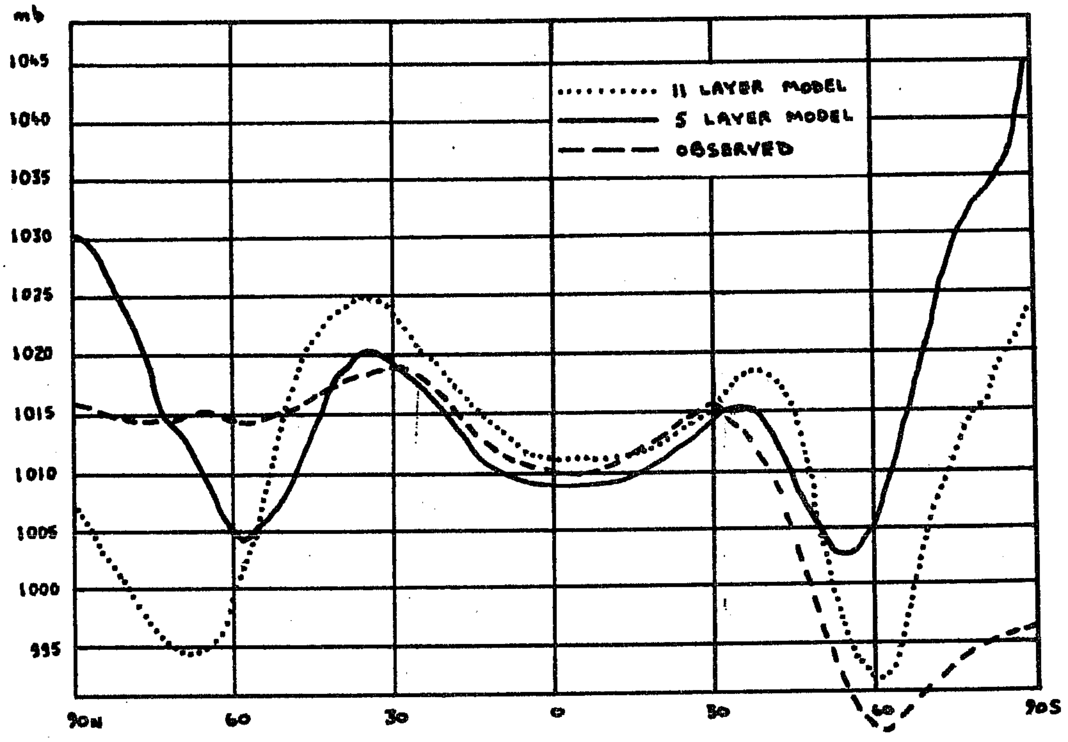
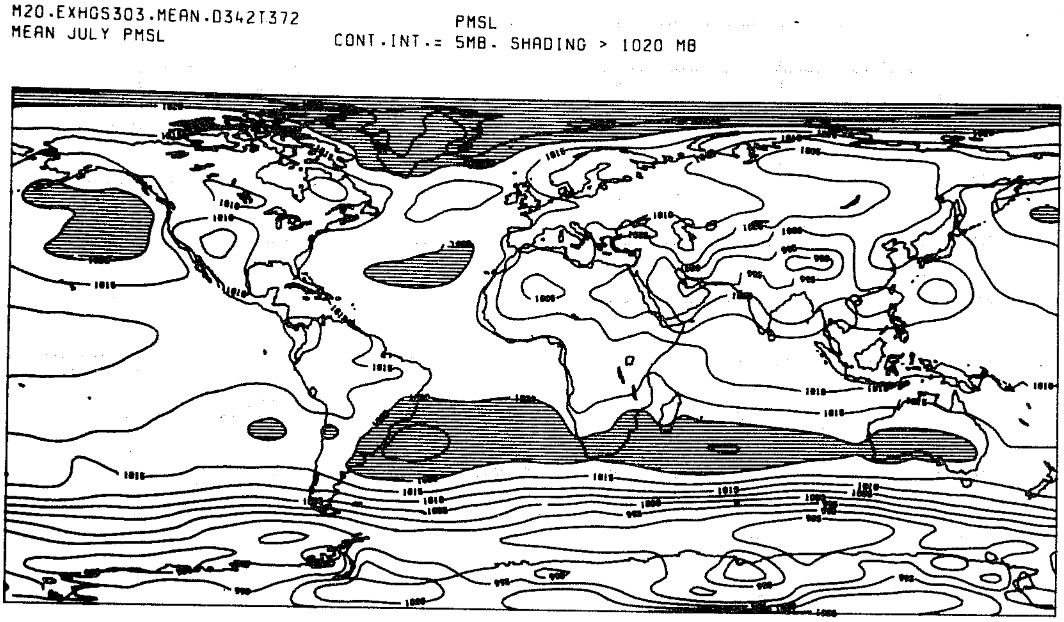


Fig.1 Zonally averaged pressure at mean sea level. Dotted line-11LM, dashed line-observed, solid line-5LM

(a) 11-layer model



(b) 5-layer model

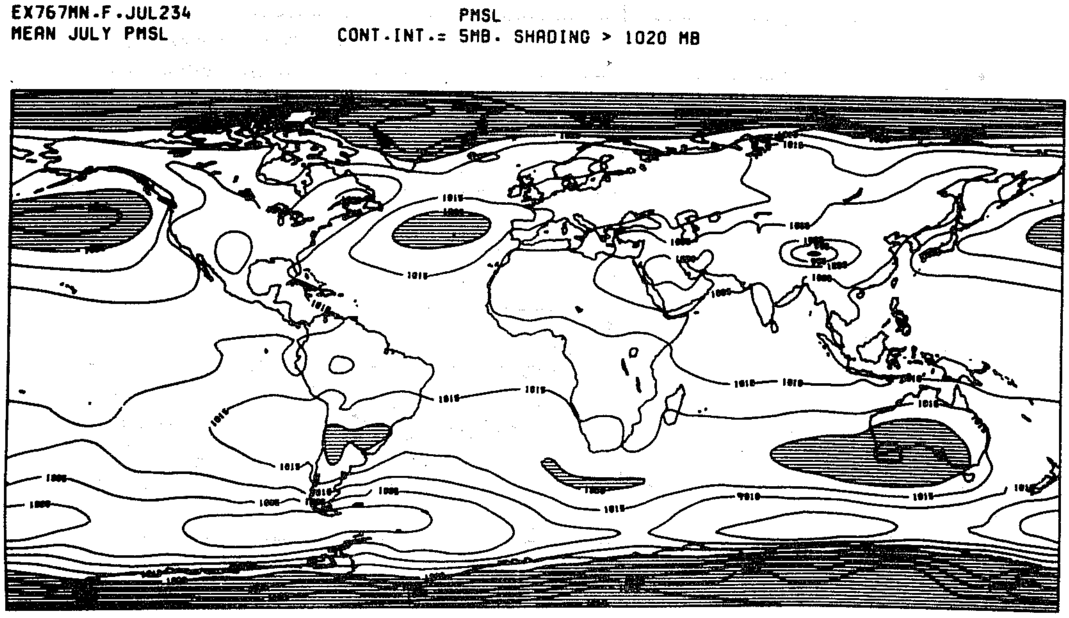


Fig.2 Monthly mean sea level pressure for July.
Contours every 5 mb, shaded where greater than 1020 mb.
(a) 11-layer model (b) 5-layer model (mean of 3 Julys).

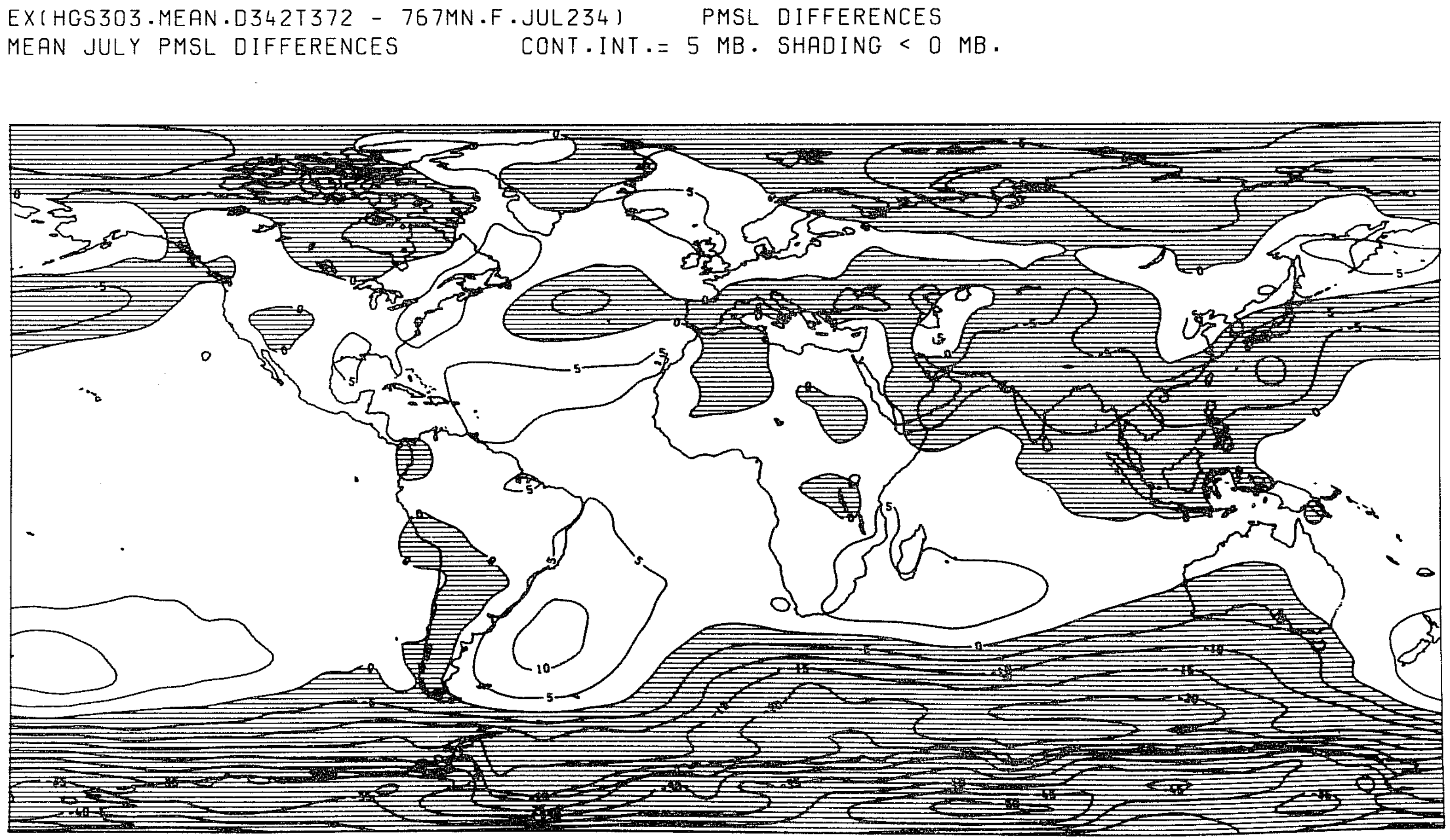


Fig.2(c) The difference (a)-(b)
Contours every 5 mb, shaded where negative.

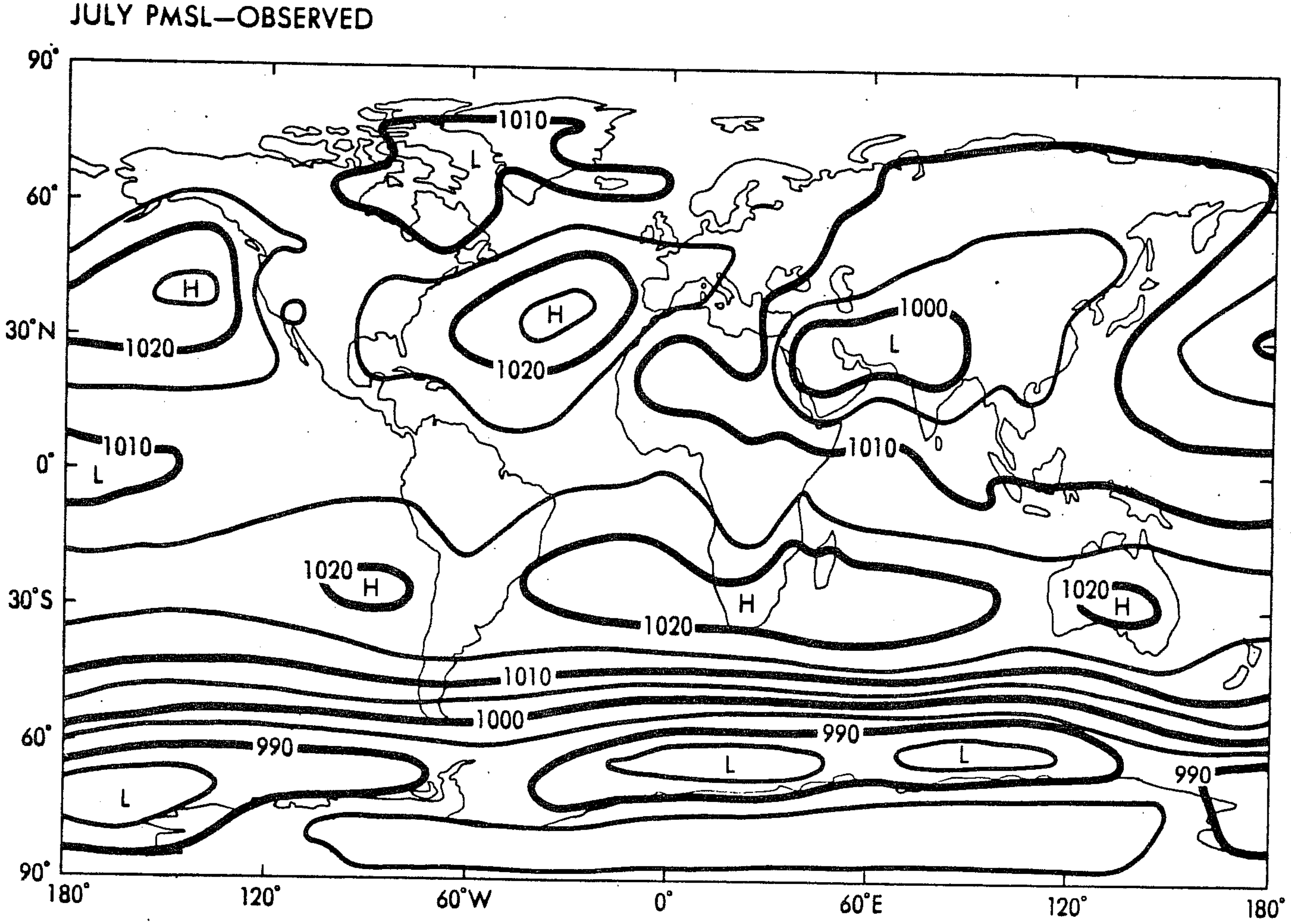
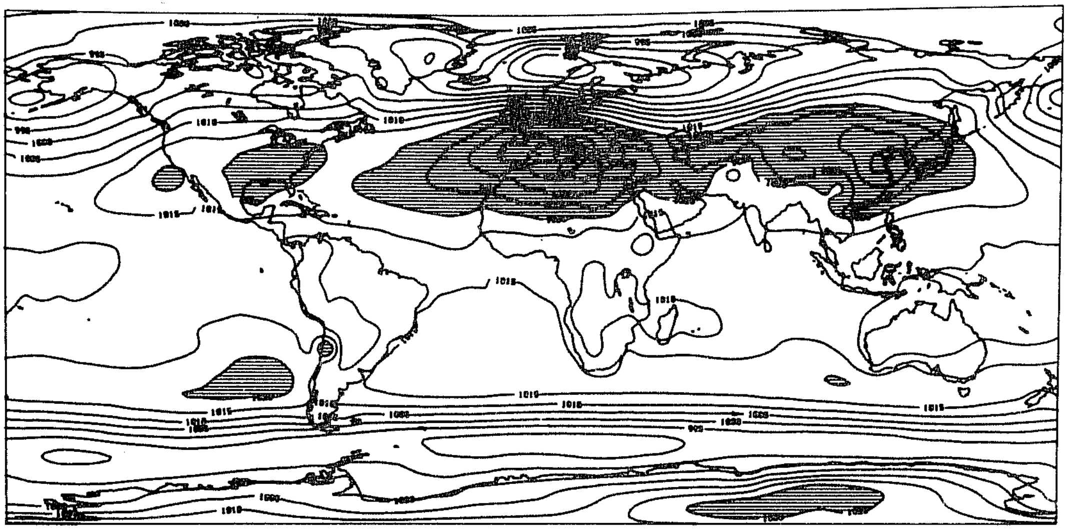


Fig.2(d) Observed July PMSL. Contours every 5 mb

(a) 11-layer model

M20.EXHGS303.MEAN.D161T091 PMSL
MEAN JANUARY PMSL CONT.INT.= 5MB. SHADING > 1020 MB



(b) 5-layer model

EX767MN.F.JAN234 PMSL
MEAN JANUARY PMSL CONT.INT.= 5MB. SHADING > 1020 MB

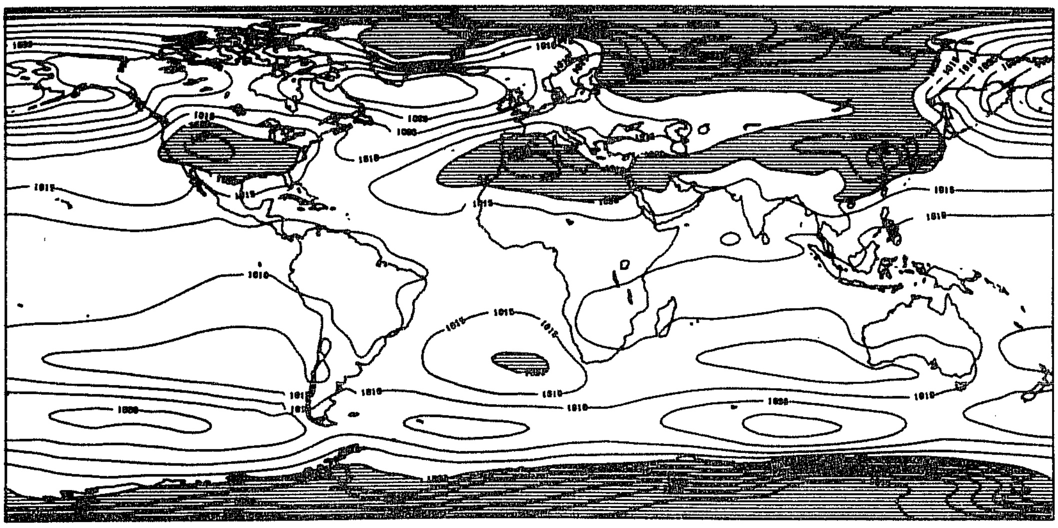


Fig.3 Monthly mean sea level pressure for January
Contours every 5 mb, shaded where greater than 1020 mb.
(a) 11-layer model (b) 5-layer model (mean of 3 Januarys)

EX(HGS303.MEAN.D161T091 - 767MN.F.JAN234)   PMSL DIFFERENCES
MEAN JANUARY PMSL DIFFERENCES   CONT.INT.= 5 MB. SHADING < 0 MB.

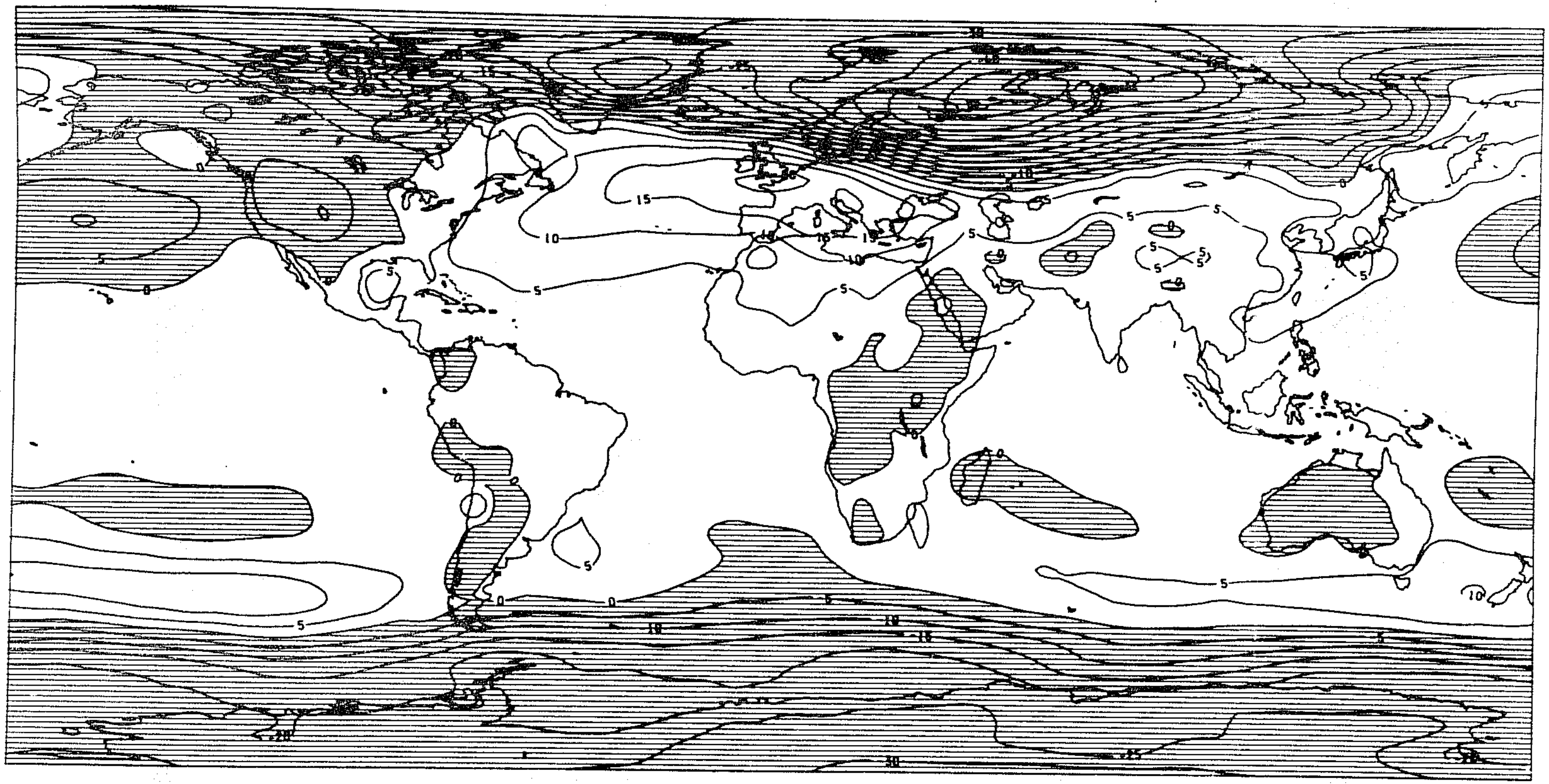
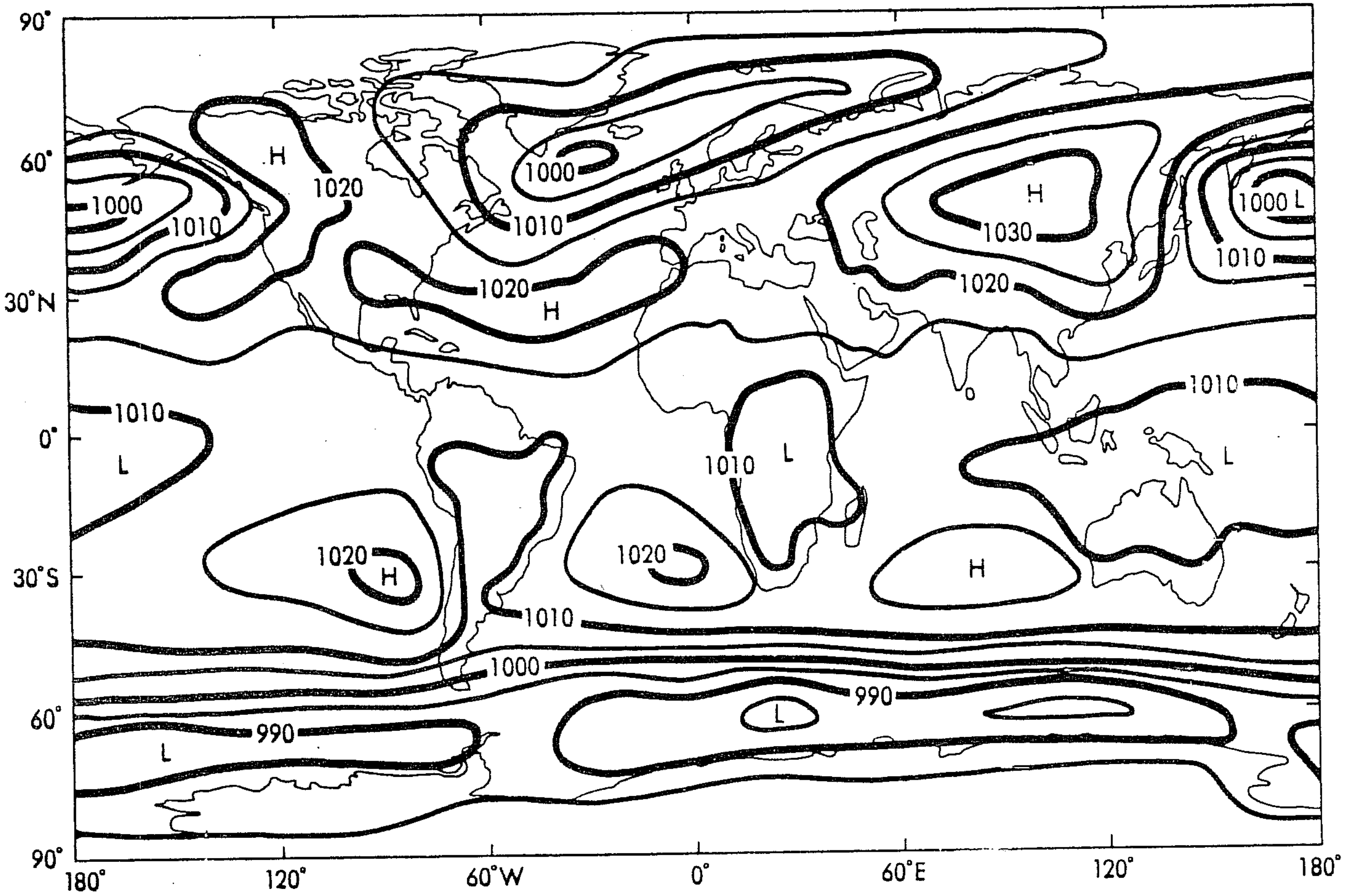


Fig.3(c) The difference (a)-(b)
Contours every 5 mb, shaded where negative



JANUARY PMSL—OBSERVED

Fig.3(d) Observed January PMSL. Contours every 5 mb.

3. Precipitation

The globally averaged annual mean precipitation rates from both models lie within the range of climatological estimates (Table 2). The 5LM has about 50% more precipitation over land than observed, whereas the 11LM has slightly less than observed. Over land, precipitation in the 5LM is heavier in the tropics and winter subtropics (Fig.4(a), (b)). Over the oceans, it is heavier in the 11LM between 10° and 30° of latitude in the summer hemisphere (Fig.4(c), (d)), and in high northern latitudes in winter where the surface pressure is lower.

If we consider differences over land in July (Fig.5), we find the net radiative heating at the surface is up to 25 WM^{-2} greater in the 5LM. It appears that in some regions the downward flux of longwave radiation is greater in the 5LM, probably because the atmosphere is moister. However, at certain latitudes in the 11LM where the surface is drier, the surface temperature is higher, and the associated increase in the upward flux of longwave radiation also contributes. (The large increase north of 60°N is due to differences in the treatment of surface albedo). The increase in surface heating may lower the surface pressure over the continents by intensifying the heat lows (see Rowntree and Walker, 1977), and increase the turbulent (latent and sensible) heat fluxes. In the tropics, increase in upward flux of latent heat in the 5LM is greater than the increase in radiative heating. This indicates that the upward flux of sensible heat is smaller in the 5LM. In other words, the 5LM converts a substantially greater fraction of the available radiant energy into latent rather than sensible heat. This could be because the surface is wetter, but a direct comparison cannot be made as the limits on soil moisture and its effect on evaporation are not the same in the two models (see Table 1.) However, by comparing

$$\beta = \frac{\text{Zonally meaned soil moisture content}}{\text{Soil moisture content for potential evaporation}}$$

Table 2

GLOBAL ANNUAL MEAN WATER BUDGETS

(mm/yr)

	LAND			SEA		ALL
	PPTN	EVAP	RUN OFF	PPTN	EVAP	PPTN
5L model	1160	595	575	1067	1387	1055
11L model	613	398	215	1278	1381	1037
Korzun (1974)	800	485	315	1270	1400	973
Baumgartner and Reichel (1973)	748	481	267	1067	1177	1130
Budyko (1970)	719	430	289	1141	1260	1020
Lvovitch and Ovchinnikov (1964)	725	483	242	1141	1241	1020
Möller (1951)	665	416	249	897	1000	832

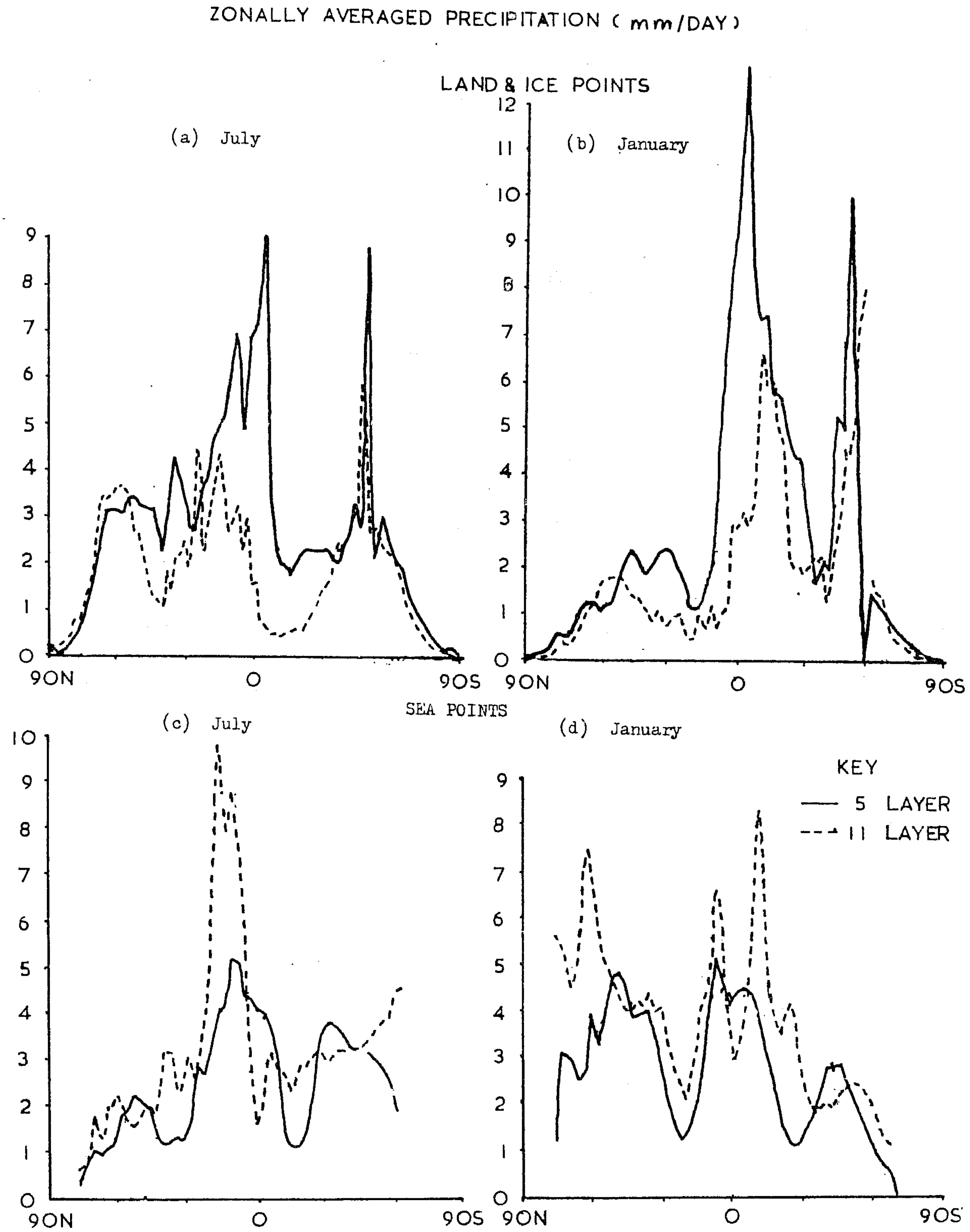


Fig.4 Zonally averaged precipitation (mm/day). Dashed line-11LM, solid line-5LM
(a) Land and ice points, July (b) Land and ice points, January
(c) Sea points, July (d) Sea points, January

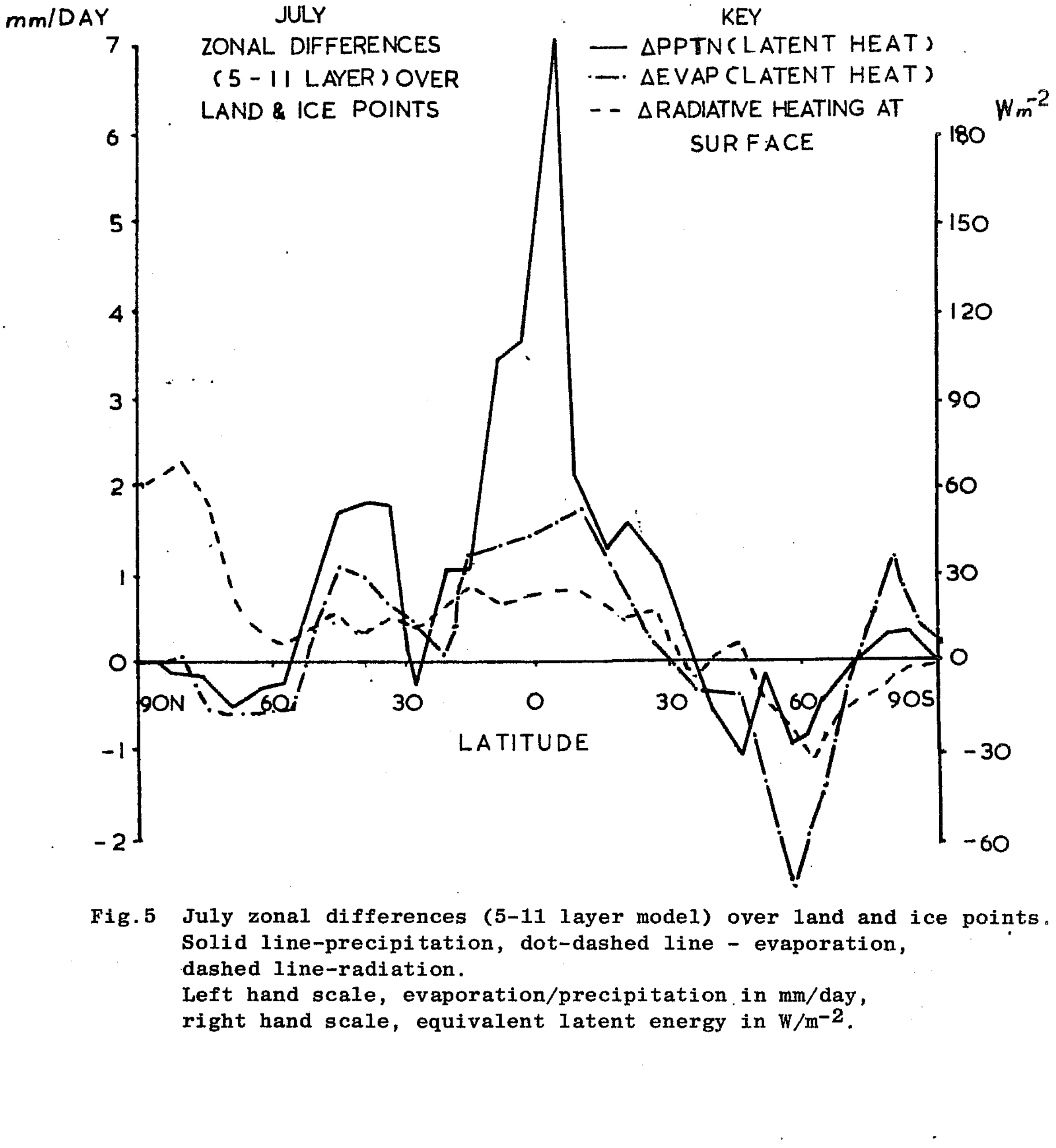


Fig.5 July zonal differences (5-11 layer model) over land and ice points. Solid line-precipitation, dot-dashed line - evaporation, dashed line-radiation.
Left hand scale, evaporation/precipitation in mm/day, right hand scale, equivalent latent energy in W/m^{-2}.

shown in Fig.6 as a function of latitude, it can be seen that the soil moisture will limit evaporation much less in the lower resolution model in the tropics and northern subtropics.

In low latitudes, the difference over land in precipitation is still greater than the difference in evaporation (Fig.5). This implies greater moisture convergence over land in the 5LM. There are local maxima in the pressure difference (11LM - 5LM) over the southeast of North America, northern Brazil, southeast Africa and the eastern coast of Asia in July (Fig.2(c)) and over northern and eastern South America, southeastern Africa in January (Fig.3(c)), indicating greater low level convergence in the 5LM. Note also the lower pressure found in the coarse grid model over Eurasia near 50°N in January. As one might expect, the 5LM produces heavier precipitation in all these regions (Figs.7(c), 8(c)). In some other tropical regions (for example, East Africa in January and parts of North Africa in July) precipitation is lighter in the 11LM, leading to high surface temperatures and shallow low level convergence with little precipitation, as discussed by Walker and Rowntree (1977).

The most striking difference in the precipitation patterns is to be found in the tropics between 60°E and 150°E. In July (Fig.7(d)), the 5LM produces excessive rainfall over the Indonesian islands, some points producing well over 40 mm/day, with rates around 5 mm/day over the ocean to the north, whereas the 11LM produces less than 5 mm/day over the islands, and substantial areas with greater than 20 mm/day over the ocean to the north. The heavier precipitation in the high resolution model is associated with lower pressure in the region from the Arabian Sea to the south of Japan. (Compare Figs. 7(c) and 2(c).). Although the 11LM is generally drier over land, this is not so over southeast Asia, the monsoon being more vigorous in the fine resolution model (Newman, 1981). Lower pressure over land and a wetter atmosphere over the ocean upwind may contribute to this anomaly. Note that the 11LM gives a trough of lower pressure in high latitudes in each hemisphere at the same longitude as the increase in tropical precipitation. Similar differences are found in January

(Fig.8). The 11LM produces heavier precipitation over the tropical oceans near 45°E, where there is also a relative trough in surface pressure (Fig.3(c)), and around the Indonesian islands.

Climatological estimates (Möller, 1951), suggests that rainfall is less than 10 mm/day over most of the ocean around Indonesia. The 11LM penetrative convection scheme appears to be the cause of this excessive precipitation. When this scheme is replaced by a convective adjustment process, the excessive rainfall rates over much of the tropical oceans are considerably reduced (Fig.9, see also Cunnington, 1979). The areas where the decrease is greater than 10 mm/day (shaded in Fig.9) largely coincide with those where precipitation is greater than 20 mm/day over the ocean (Fig.6(a)). There are, however, increases in precipitation over Southeast Asia and parts of the tropical Pacific Ocean.

Rowntree and Cunnington (private communication) have recently investigated the sensitivity of precipitation to changes in the evaporation of convective rainfall using a version of the 11 layr model on a 2° x 3° latitude longitude horizontal grid. The evaporation is proportional to the humidity deficit in the layer through which the precipitation is falling. When no evaporation is allowed, they find that the excessive precipitation over the tropical oceans is largely removed, and there is on average an increase in precipitation over the tropical continents.

The distribution of rainfall is closer to that of the 5 layer model, where the coefficient of proportionality used in the evaporation of precipitation is much smaller than in the original 5 layer model. Although this partly explains the differences in tropical rainfall between the low and high resolution models, it should be remembered that there are other differences in treatment of convection, and in other aspects of the model which could contribute.

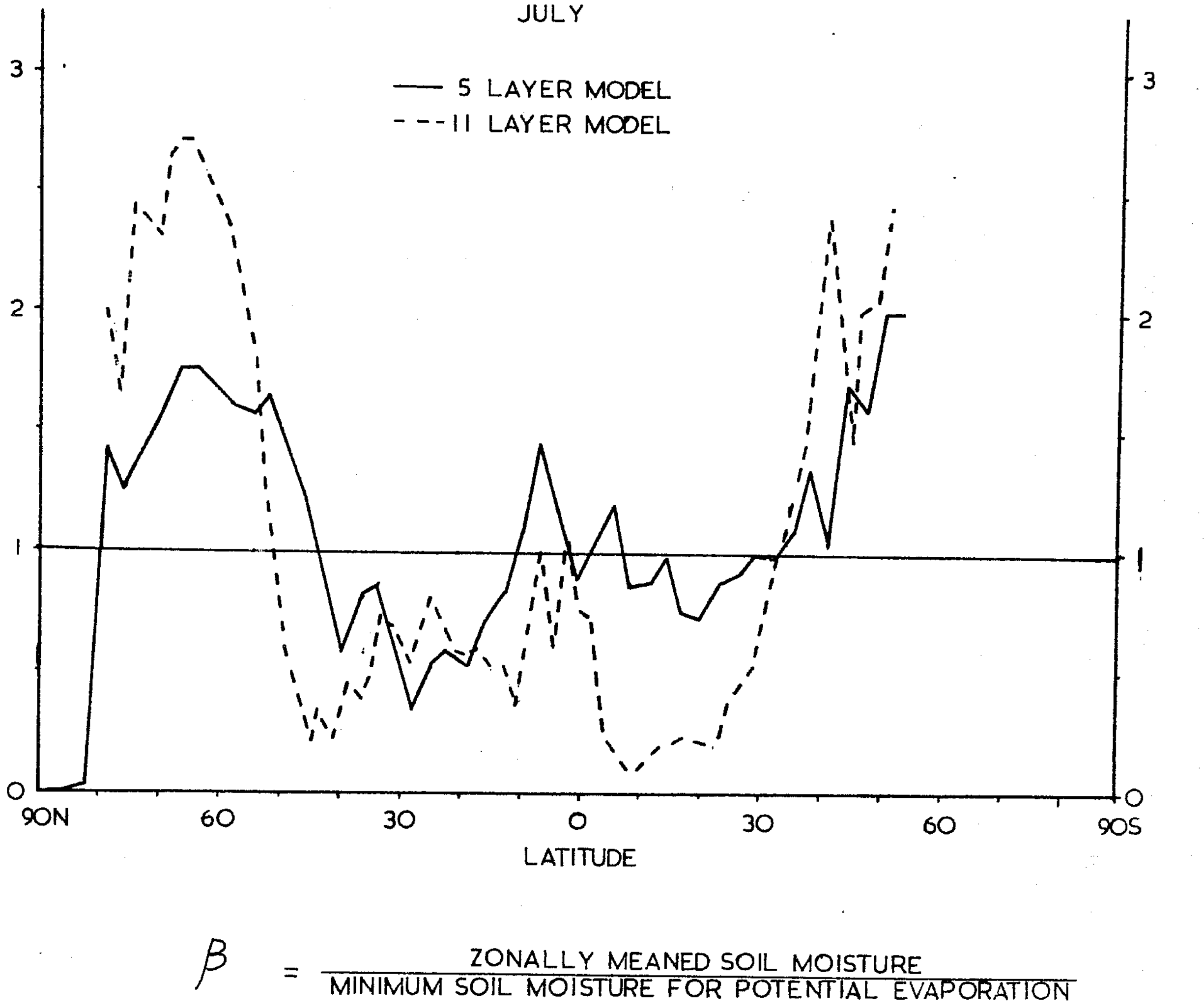
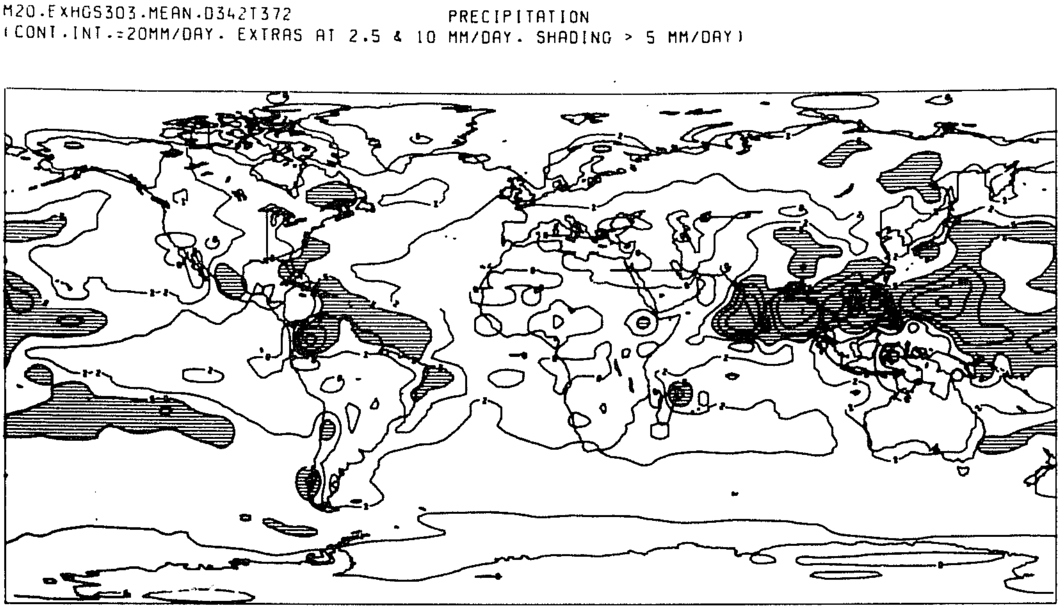


Fig.6 β for the 5 layer model (solid line) and the 11 layer model (dashed line) as a function of latitude.

(a) 11-layer model



(b) 5-layer model

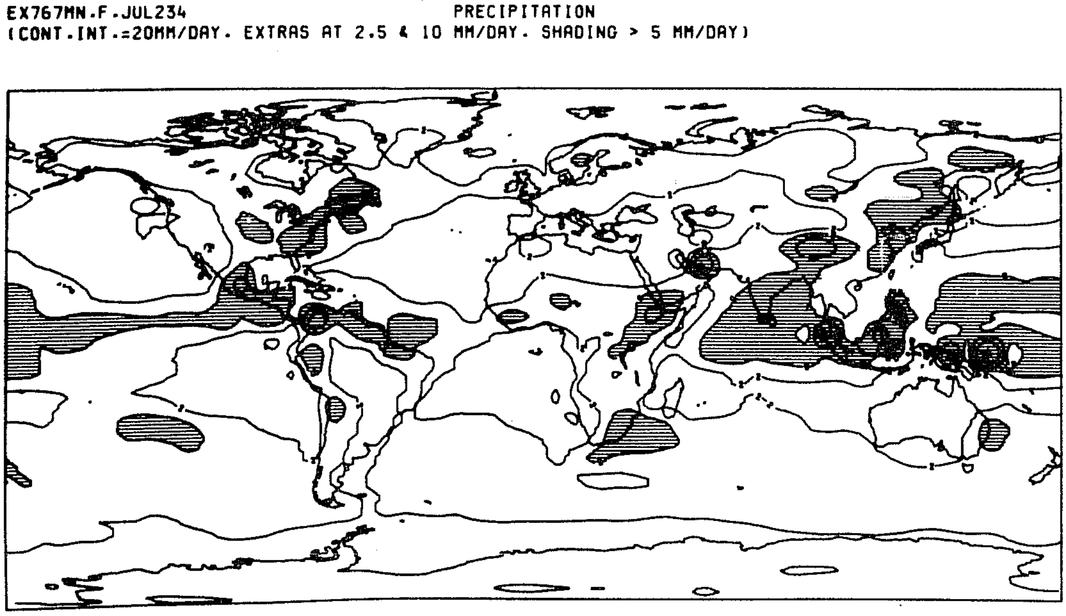


Fig.7 Monthly mean precipitation for July
Contours at 2, 5, 10, 20, 40 mm/day, shaded where greater than 5 mm/day.
(a) 11-layer model (b) 5-layer model (3 year mean)

EX(HGS303.MEAN.D342T372 - 767MN.F.JUL234)   PRECIPITATION DIFFERENCES
(CONT.INT.=20MM/DAY. EXTRAS AT 2.5 & 10 MM/DAY. SHADING < 0 MM/DAY)

Fig.7c The difference (a)-(b)
Contours at 0, ±2, ±5, ±10, ±20, ±40 mm/day, shaded where negative

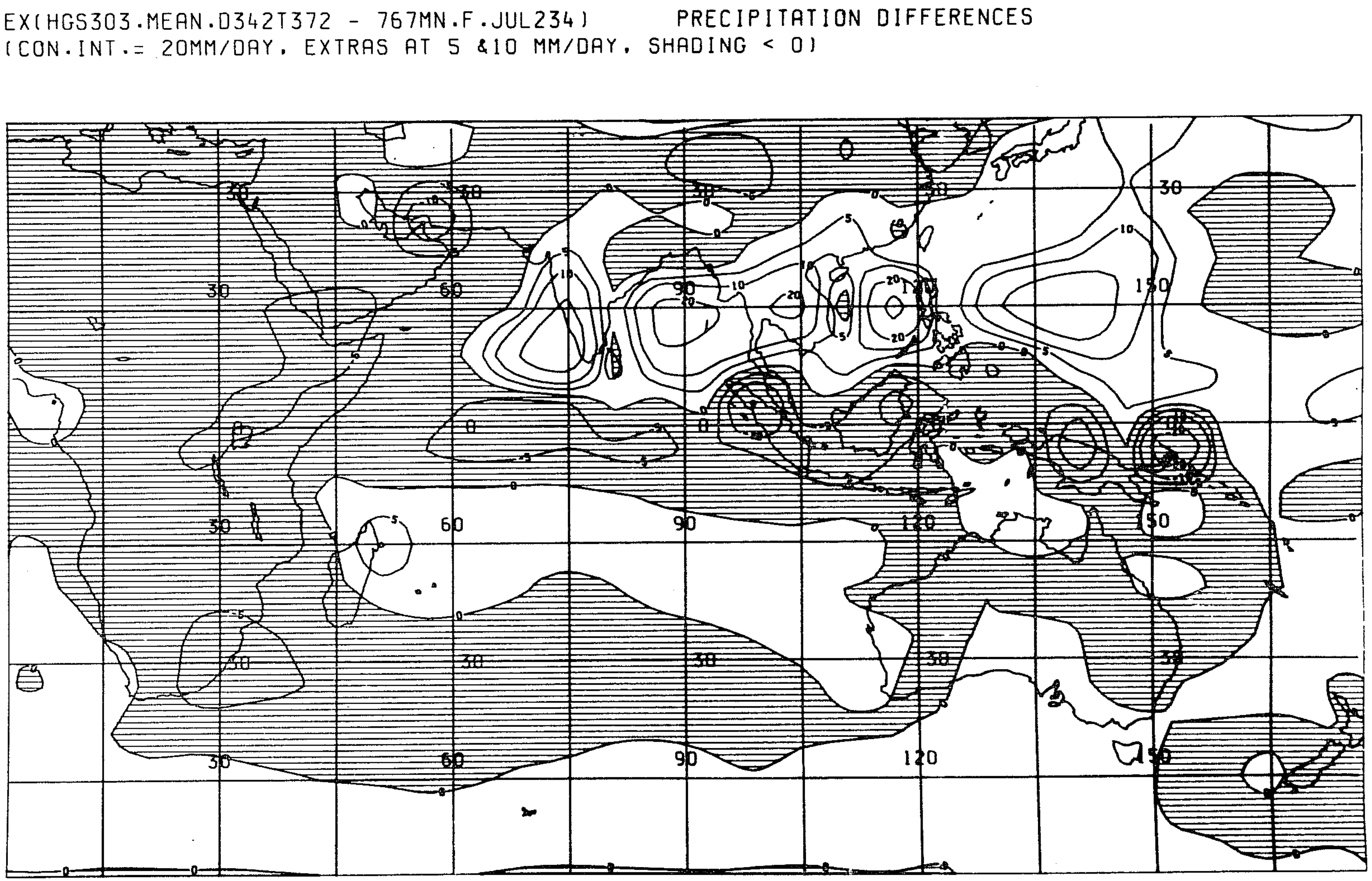
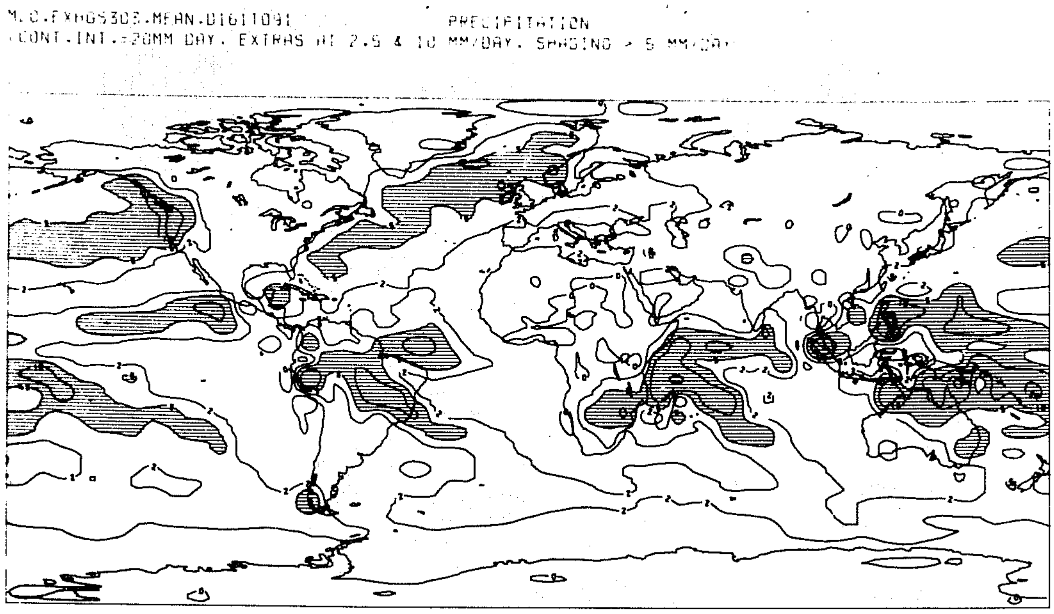


Fig.7(d) As (c), but over the eastern tropics.
Contours at 0, ±5, ±10, ±20 and ±40 mm/day, shaded where negative.

(a) 11-layer model



(b) 5-layer model

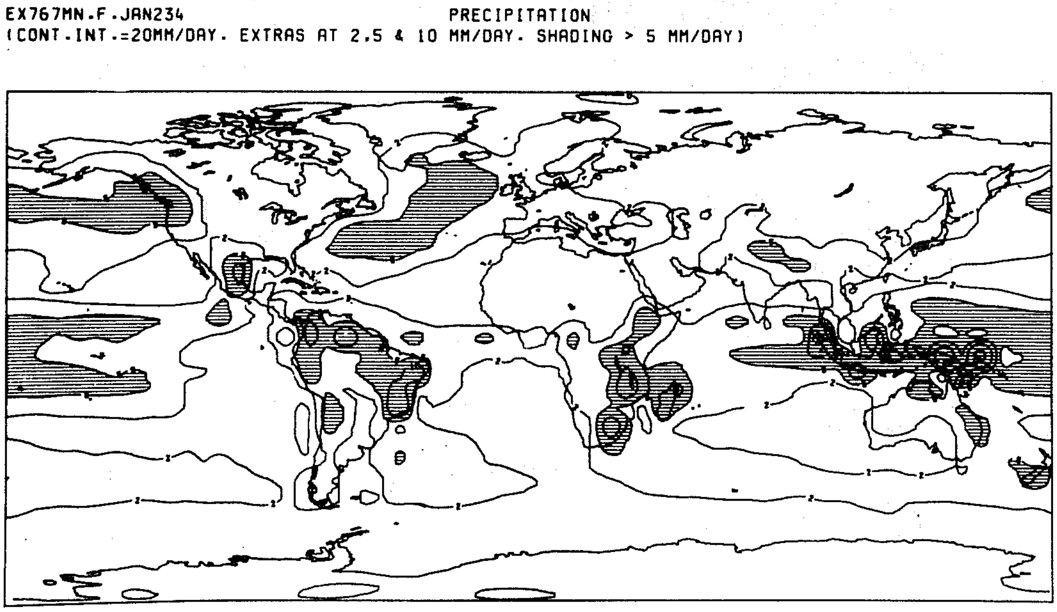


Fig.8 Monthly mean precipitation for January.
Contours at 2, 5, 10, 20 and 10 mm/day, shaded where greater than 5 mm/day.
(a) 11 layer model (b) 5 layer model (3 year mean)

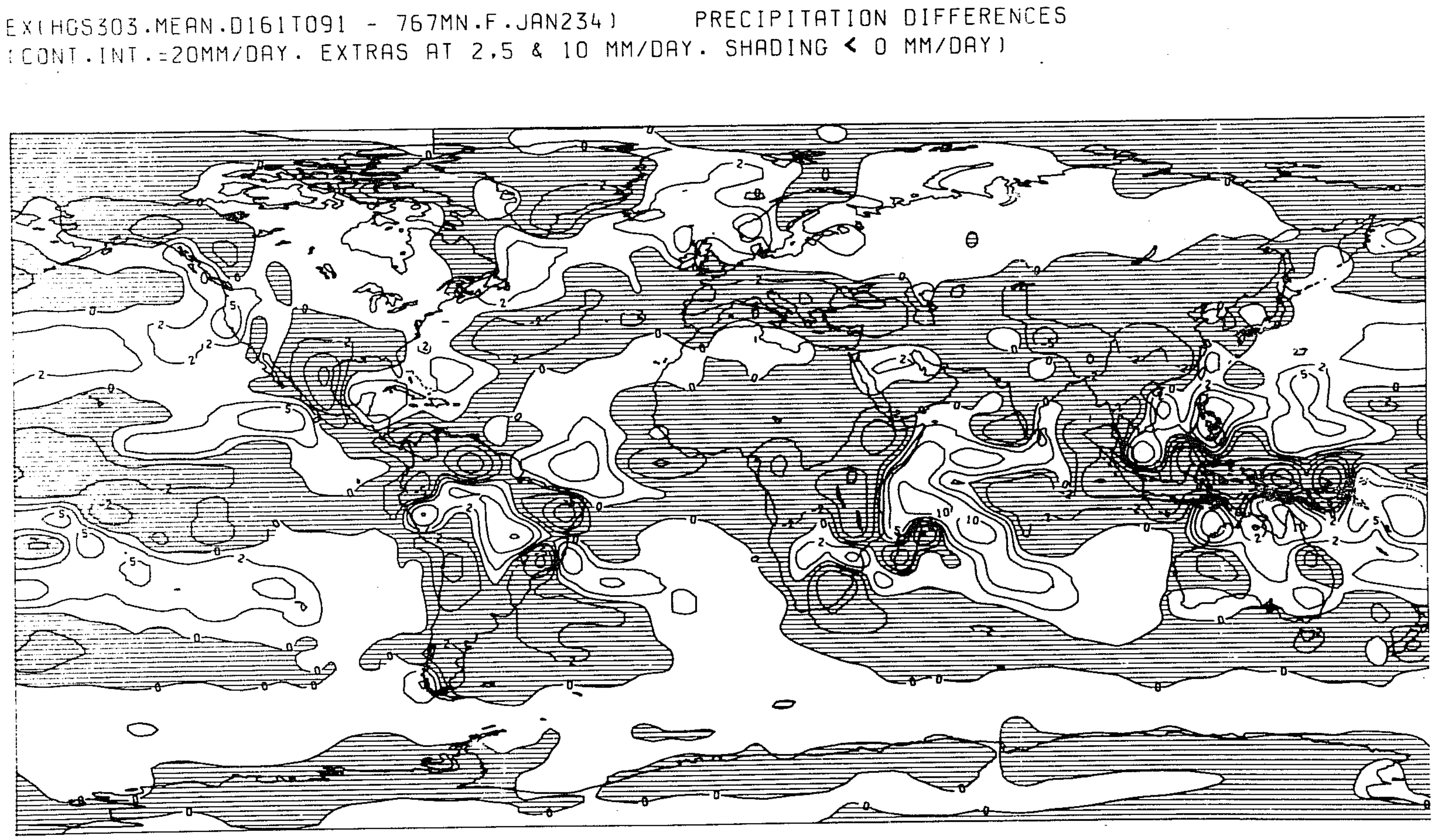


Fig.8(c) The difference (a)-(b)
Contours at 0, ±2, ±5, ±10, ±20, ±40 mm/day, shaded where negative.

EX(HGS303.MEAN.D161T091 - 767MN.F.JAN234) PRECIPITATION DIFFERENCES
(CON.INT.= 20MM/DAY, EXTRAS AT 5 &10 MM/DAY, SHADING < 0)

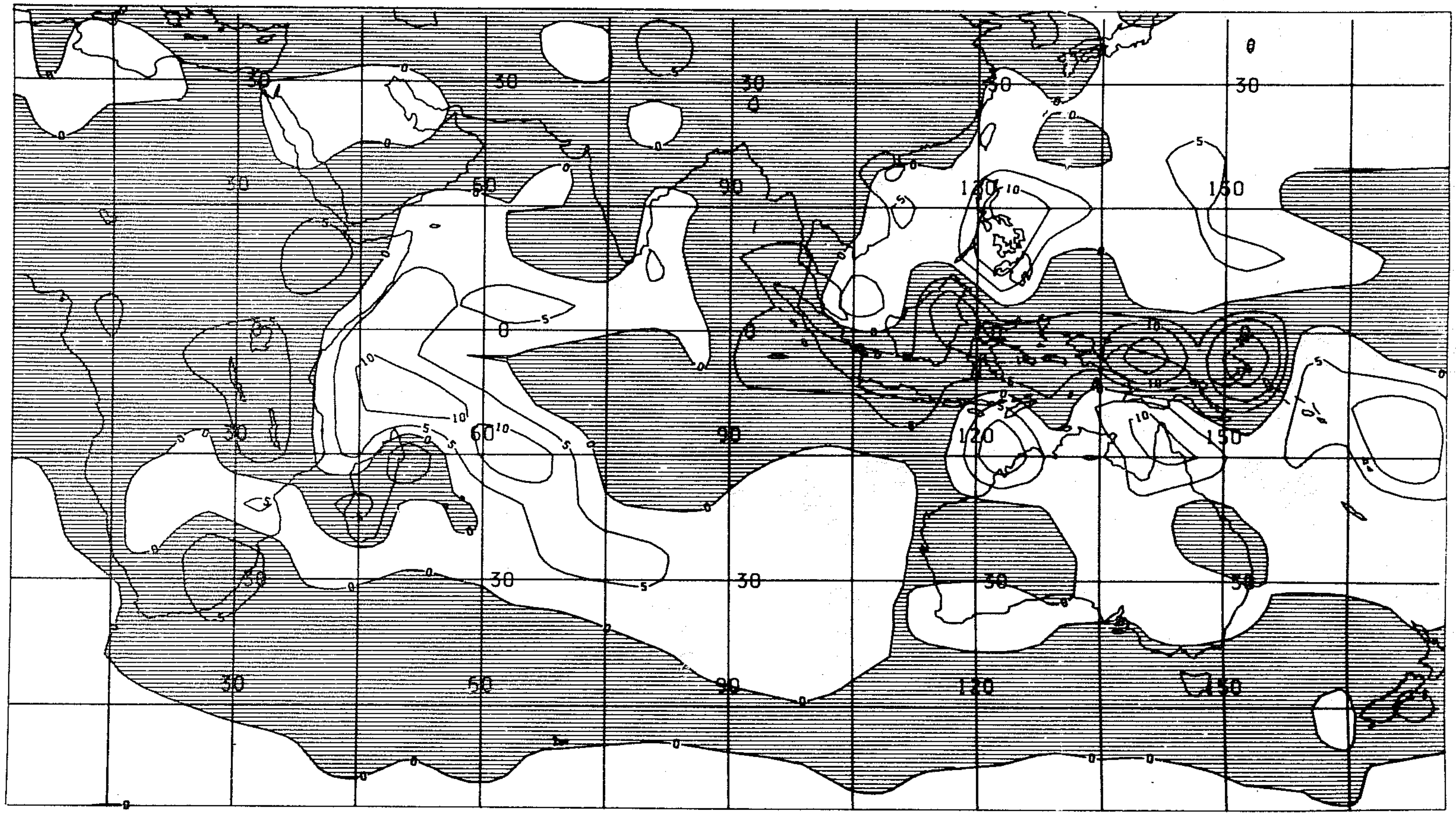


Fig.8(d) As (c), but over the eastern tropics.
Contours at 0, ±5, ±10, ±20, ±40 mm/day, shaded where negative.

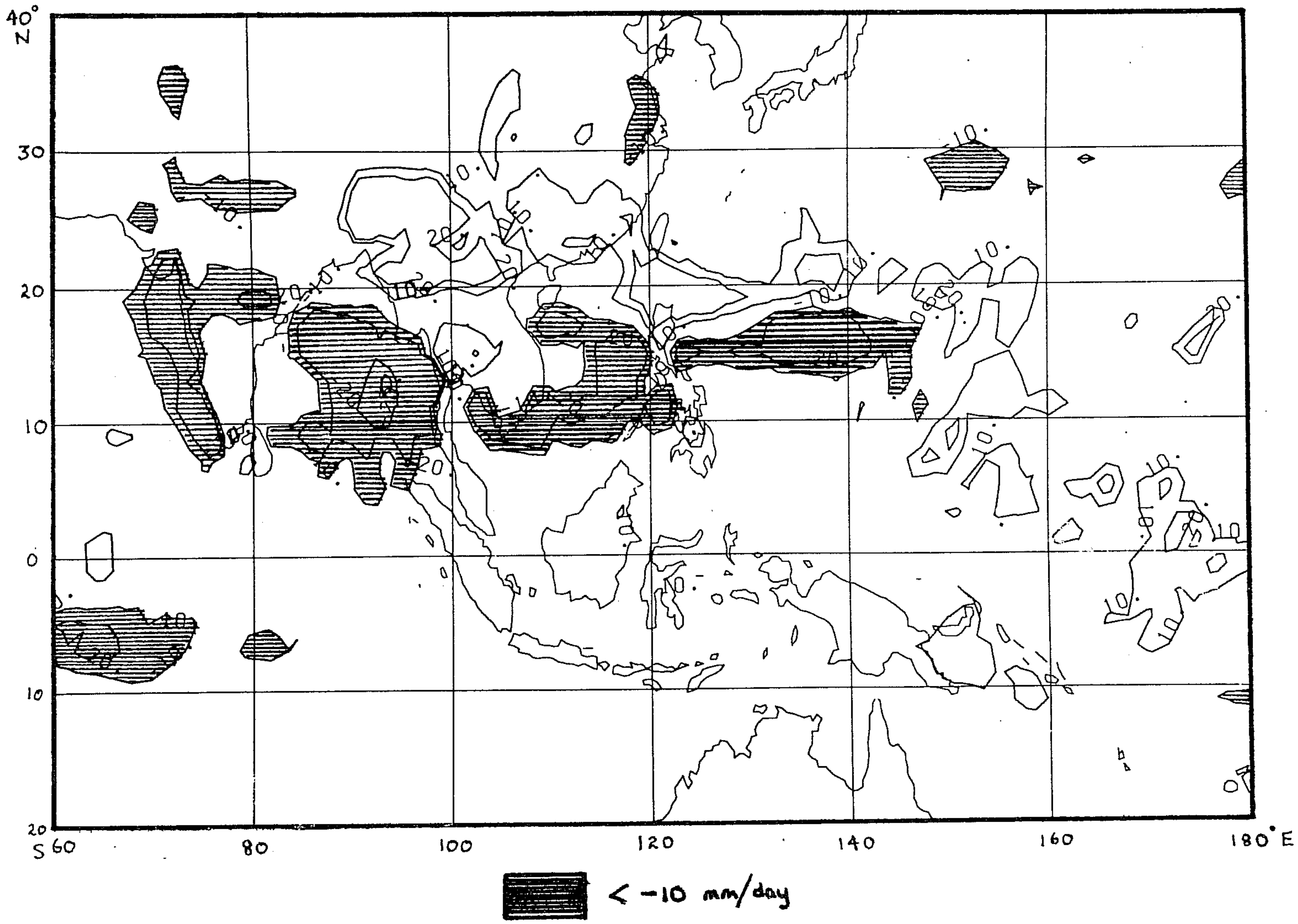


Fig.9 Differences in July precipitation (Convective Adjustment - Penetrative Convection) in the 11-layer model (mm/day). Shaded where the differences (PC-PA) are greater than 10 mm/day. Contours ±10 mm/day, ±20 mm/day. (eastern tropics only).

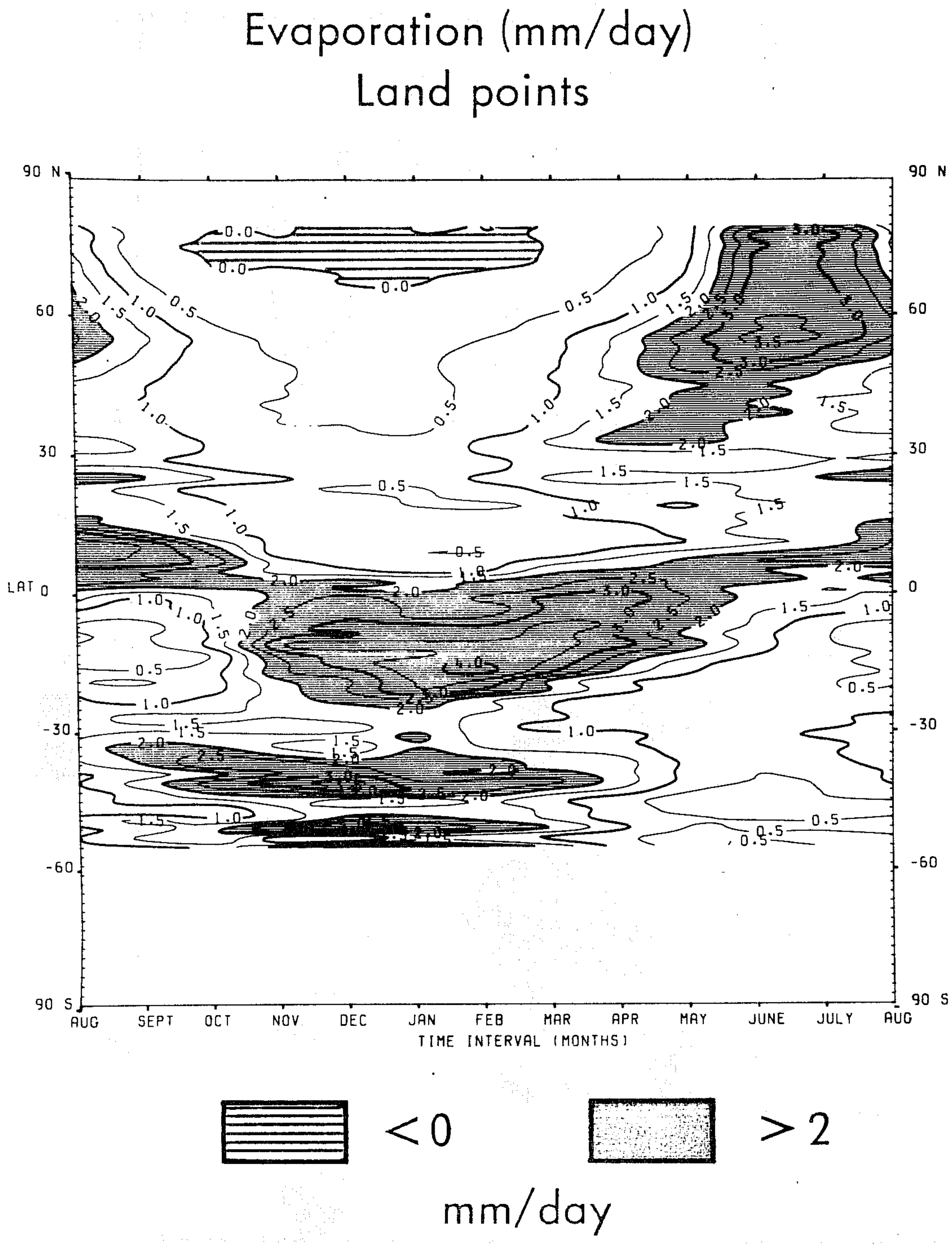


Fig.10(a) Time latitude diagrams of evaporation from the land surfaces of the 11-layer model. Contours every 0.5 mm/day, dark shading where >2.0 mm/day, light shading where <0.0 mm/day.

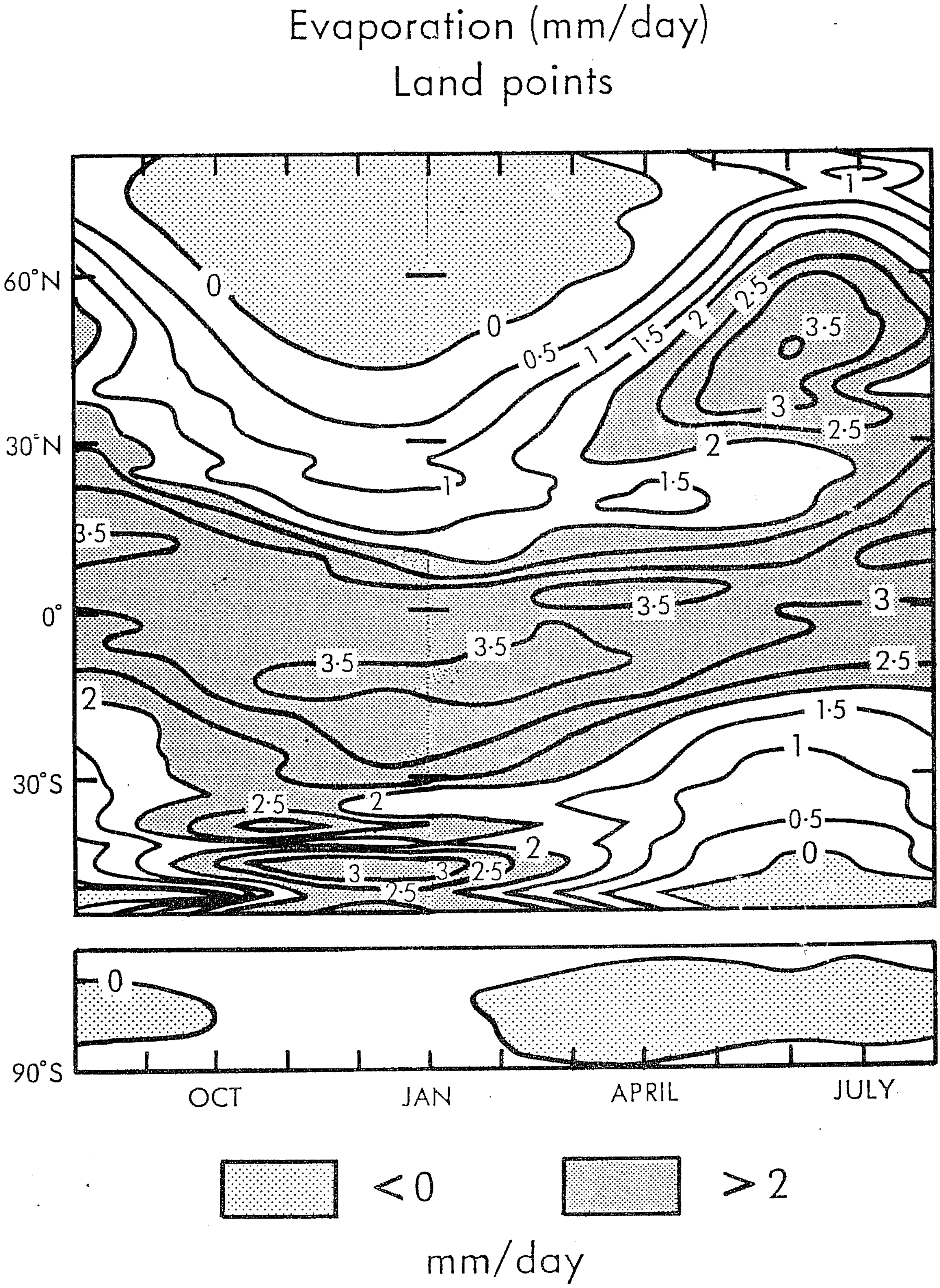


Fig.10(b) As Fig.(10(a), but for the 5-layer model.

4. Evaporation

The geographical distribution of differences in evaporation over land is reasonably zonal, and hence is not shown. One can see from the time-latitude diagrams (Fig.10) that the 5LM gives more evaporation at most latitudes between 30°S and 30°N (50° in northern summer). In low latitudes the differences are smallest in the summer hemisphere, when there is an abundant supply of moisture to the surface in monsoon rainfall, and are greatest in the winter hemisphere, when precipitation is light and the surface dries out. Note that the soil moisture in the 11LM is limited to 15 cm, and so it cannot accumulate as much moisture in the rainy season. One can see in Fig.10(a) that evaporation has decreased in low latitudes during the course of the year. There is little systematic difference in the zonal means of evaporation over the oceans from these two models.

5. Summary

The 11LM generates lower pressure in high latitudes and southern mid-latitudes than the 5LM, and produces much stronger westerly flow over Europe and northern Asia in winter. Precipitation rates over the tropical oceans are unrealistically high in the 11LM, probably as a result of the penetrative convection scheme used, whereas in the 5LM, precipitation over land is 50% higher than observed. The higher continental precipitation is probably due in part to greater evaporation and increased low level convergence. There is more evaporation as the surface is effectively "wetter", and there is more radiant energy available at the surface for conversion into latent heat.

The excessive westerly flow in northern mid-latitudes in winter and the excessive precipitation over the tropical oceans are serious shortcomings which should be investigated as soon as possible.

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